

# Electrotherapy in Tissue Repair

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Research into treatment techniques for tissue repair has undergone tremendous discussion and growth in recent years. There are many treatment facets to consider when addressing the healing process. Treatment options may range in scale from global concerns to effects produced at a cellular level. Global tissue repair issues include health care coverage, reimbursement, and the interaction of health care professionals on a wound care team. Client-centered matters may also affect healing. For example, health care professionals may choose to use a team approach including the client, family, and other care givers in the management of tissue healing. Other client-centered factors that affect the healing process include injury, disease, nutrition, and compliance. Last, there are treatment components affecting the tissue or wound environment. Previous articles in this journal have covered many cellular aspects of tissue and wound environment issues with regard to tissue healing and repair.

Electrotherapy influences tissue repair at the level of the wound environment. This article discusses research findings and the clinical use of electrotherapy in tissue repair. A brief review of the theories and current scientific rationale for use of electrotherapy in tissue healing is provided. Included is a brief examination of research dealing with electrotherapy and tissue healing. Clinical treatment decisions—involving types of electrical current, polarity, electrode placement, and other parameters as well as precautions and contraindications—are discussed. This article summarizes recent developments and trends in the use of electrotherapy for tissue repair in order to facilitate clinicians' decision-making capabilities and their understanding of treatment options.

## THEORETIC AND SCIENTIFIC BASIS

A number of interesting and thought-provoking studies of electrotherapy and tissue repair have been done in recent years. In light of this research, possible mechanisms attributed to electrotherapy and the stimulation of tissue repair are examined

here, starting with the theory of skin battery voltage and healing.

Numerous studies<sup>1-6</sup> have shown that tissues in living organisms possess an electrical current. Various living organisms, including humans, have a skin battery potential that is negatively charged on the surface (skin) and positively charged in deeper tissues.<sup>7-10</sup> Research has demonstrated the presence of an electrical current in the wounds and injuries of human beings and other living organisms.<sup>11,12</sup> Intact skin has a small negative charge, and wounds are positively charged. Becker<sup>13</sup> introduced the concept of a "current of injury" and demonstrated the difference in charges in the skin and on its surface. Vanable<sup>14</sup> has demonstrated that mammalian skin requires a moist environment to maintain this flow of current in the tissue. Cheng et al.<sup>15</sup> have also demonstrated that wounds protected and kept moist with an occlusive dressing have higher levels of voltage than wounds exposed to the air. These findings lend credence to research supporting the need for a moist environment for optimal healing of tissue.<sup>16,17</sup> In summary, there appears to be a relationship between the electrical "current of injury" and the repair, regeneration, and growth of tissue. Electrotherapy may mimic the body's own bioelectrical signal and promote healing in chronic wounds that have an impaired or insufficient "current of injury."

Research findings have provided a basis for the use of electrotherapy to augment the healing process. Many effects of electrotherapy on the healing of wounds have been reported. An extensive review of the electrotherapy and tissue healing literature is not provided here, but a synopsis of pertinent human and animal research on the effects of electrotherapy appears in Table 1. Previous articles in this journal have reviewed the different phases of healing—the inflammatory, proliferative or fibroplastic, and remodeling or maturation phases—and have illustrated many elements of both successful and abnormal healing processes. As discussed in these articles, such factors as the cells involved, the physiologic or metabolic factors, and the presence of inflammation or edema may affect the healing process.

Cellular effects that may promote healing include the attraction and stimulation of neutrophils, macrophages, leukocytes, and fibroblasts to the area of the wound.\* Electrotherapy has also been

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\*References 20-23, 26, 28, 29, 32, 35, 42, 43, and 45.

TABLE 1. Effects of Electrotherapy on Tissue Repair

Cellular effects	
Epidermal cell migration <sup>10,18,19</sup>	
Increased fibroblast proliferation <sup>20</sup>	
Anode:	
Neutrophils attracted <sup>21,22</sup>	
Macrophages attracted <sup>23</sup>	
Mast cells (associated with abnormal fibrotic healing) migration inhibited <sup>24,25</sup>	
Leukocytes attracted <sup>26</sup>	
Thrombosis of small vessels <sup>26</sup>	
Bactericidal <sup>27</sup>	
Cathode:	
Neutrophils attracted <sup>21,22</sup>	
Fibroblasts attracted <sup>28,29</sup>	
Epidermal cell migration <sup>30,31</sup>	
Leukocytes attracted (when infection/inflammation present) <sup>21,32,35</sup>	
Increased blood flow <sup>33,34</sup>	
Decreased edema <sup>36</sup>	
Solubilization of thrombus material <sup>39</sup>	
Bactericidal <sup>38,39,40</sup>	
Physiologic/metabolic effects	
Increased adenosine triphosphate concentration <sup>41</sup>	
Increased collagen alignment or organization <sup>29,42,43</sup>	
Increased protein synthesis and DNA production <sup>43</sup>	
Increased amino acid uptake <sup>41</sup>	
Increased collagen synthesis <sup>45</sup>	
Stimulation of growth factor receptor sites <sup>46</sup>	
Prevention of oxygen-derived free radical damage <sup>47</sup>	
Bactericidal/antimicrobial effects	
<i>Pseudomonas aeruginosa</i> <sup>27,48,49,50</sup>	
<i>Staphylococcus aureus</i> <sup>27,40,50</sup>	
<i>Escherichia coli</i> <sup>27,50,52</sup>	
<i>Staphylococcus epidermidis</i> <sup>51</sup>	
<i>Klebsiella</i> organisms <sup>50</sup>	
Gram-positive, gram-negative bacteria and yeast <sup>52</sup>	
Cellular attraction of macrophages, leukocytes, and neutrophils	
Circulatory effects	
Decreased edema <sup>36,53</sup>	
Improved circulation <sup>33-36,54,55</sup>	
Improved blood flow to grafts/flaps <sup>47,56-58</sup>	
Other tissue effects	
Improved healing rates (see Table 2)	
Improved epithelialization <sup>45</sup>	
Solubilization of thrombus material at cathode <sup>37</sup>	
Decreased scar thickness <sup>24,25</sup>	
Improved tensile strength <sup>59,60</sup>	

shown to cause beneficial changes in blood flow and reduction in edema.<sup>33-36,47,54-58</sup> Physiologic and metabolic effects may involve improved protein and collagen synthesis<sup>29,42,43,45</sup> as well as valuable effects on adenosine triphosphate and DNA production and on amino acid uptake. Research has shown that the use of electrotherapy may provide bactericidal or bacteriostatic effects as well.<sup>†</sup>

A good number of clinical human studies have demonstrated the effectiveness of electrotherapy in the enhancement of healing, as summarized in Table 2 (see pp. 134 and 135). These studies utilized the following types of electrical currents: continuous microamperage direct current, pulsed microamperage direct current, pulsed milliamperage current, and high-voltage pulsed current (HVPC).

Currently, HVPC appears to be the most thoroughly researched of the electrotherapy currents available. Research on its effects on wound healing includes clinical, animal, and in vitro studies.

As Table 2 shows, many studies support the use of electrical current in the treatment of chronic wounds. In 1994, the Agency for Health Care Policy and Research (AHCPR) published a guideline for the treatment of pressure ulcers,<sup>78</sup> which was developed by a panel of pressure ulcer experts and was based on scientific findings and expert clinical experience. The panel recommended that clinicians "consider a course of treatment with electrotherapy for stage III and IV pressure ulcers that have proved unresponsive to conventional therapy. Electrical stimulation may also be useful for recalcitrant stage II ulcers." The studies on which these recommendations are based<sup>63,69,70,74,77</sup> are also included in Table 2.

## TREATMENT CONSIDERATIONS AND PROCEDURES

### Current Types

Table 2 provides a review of some of the studies in which electrical currents have been used in the treatment of wounds to promote tissue healing and repair. The following types of current—continuous microamperage direct current, pulsed microamperage direct current, pulsed milliamperage current, and HVPC—have all been shown to enhance wound healing.<sup>61-77</sup> Figure 1 represents these currents graphically.

When continuous microamperage direct current is used to treat a wound, the clinician may utilize a positive electrode (anode) or a negative one (cathode). The anode may attract neutrophils and macrophages as well as cause clotting.<sup>21-23,26</sup> The cathode may attract neutrophils, fibroblasts, and leukocytes to the area.<sup>21,22,28,29,32,35</sup> These cells speed healing, self-debridement, and autolysis of the wound. The solubilization of thrombic material at the cathode also aids in wound debridement.<sup>39</sup> Cathode stimulation has also been shown to enhance epidermal cell migration.<sup>30,31</sup> Both the anode and cathode may provide a bactericidal effect.<sup>37-40</sup> (See Table 1 for more effects of anode and cathode stimulation.) A protocol for the use of microamperage direct current is described by Kloth<sup>79</sup>: If the wound is infected, the cathode is placed on the wound and the anode is placed at least 15 cm proximal to it; parameters include 200–1,000  $\mu$ A for two to four hours a day, three to seven days a week. When infection has cleared, the anode should be placed in the wound, and polarity may be reversed daily or every three days if healing plateaus.

Pulsed microamperage direct current was used in two studies cited in Table 2. Both Barron et al.<sup>65</sup> and Wood et al.<sup>66</sup> used probes to deliver pulsed microamperage direct current. (See Table 2 for the parameters.) Additional studies are required to sup-

†References 12–23, 26, 27, 32, 35, 40, 48, and 52.

port the use of this type of current and mode of delivery.

In an example of the use of pulsed milliamperage direct current, Kaada<sup>67</sup> used a transcutaneous electrical nerve stimulator (TENS) in the burst mode (2 bps) to treat the web spaces of the hands of subjects with lower-extremity ulcers. The author applied 15–30 mA of pulsed direct current for 30–45 minutes three times a day, with the cathode placed on the ipsilateral web space of the hands of the subjects. Using this procedure he attained 100% healing of the wounds of the ten treated subjects. Feedar et al.<sup>69</sup> conducted a prospective, randomized, multicenter, controlled study of pulsed milliamperage direct current. They treated stage III and stage IV chronic ulcers with pulsed direct-current cathode stimulation at 128 pps, with a peak amplitude of 29.2 mA, for 30 minutes two times a day for seven days a week. After debridement or when serosanguinous drainage appeared, the polarity was switched every

three days until the wounds could be classified stage II. At this point, the frequency was dropped to 64 pps to prevent overstimulation of the healing tissue. Polarity was then switched daily. (See Table 2 for the complete, successful results of this study.) Gentzkow et al.,<sup>70</sup> using a similar procedure for the electrotherapeutic application of milliamperage direct current, also had notable wound healing results (Table 2).

Studies involving HVPC and tissue healing are also highlighted on Table 2. Kloth and McCulloch<sup>80</sup> present a protocol for HVPC using the anode on the wound to promote autolysis and epithelialization and using the cathode to treat infection and inflammation and promote granulation. According to this protocol, the nontreatment electrode is placed adjacent to the treatment electrode on intact skin. The frequency of HVPC should be 100 pps, and for skin with intact sensation, the amplitude should be set at a level to produce a tingling sensation (submotor response); for skin with impaired

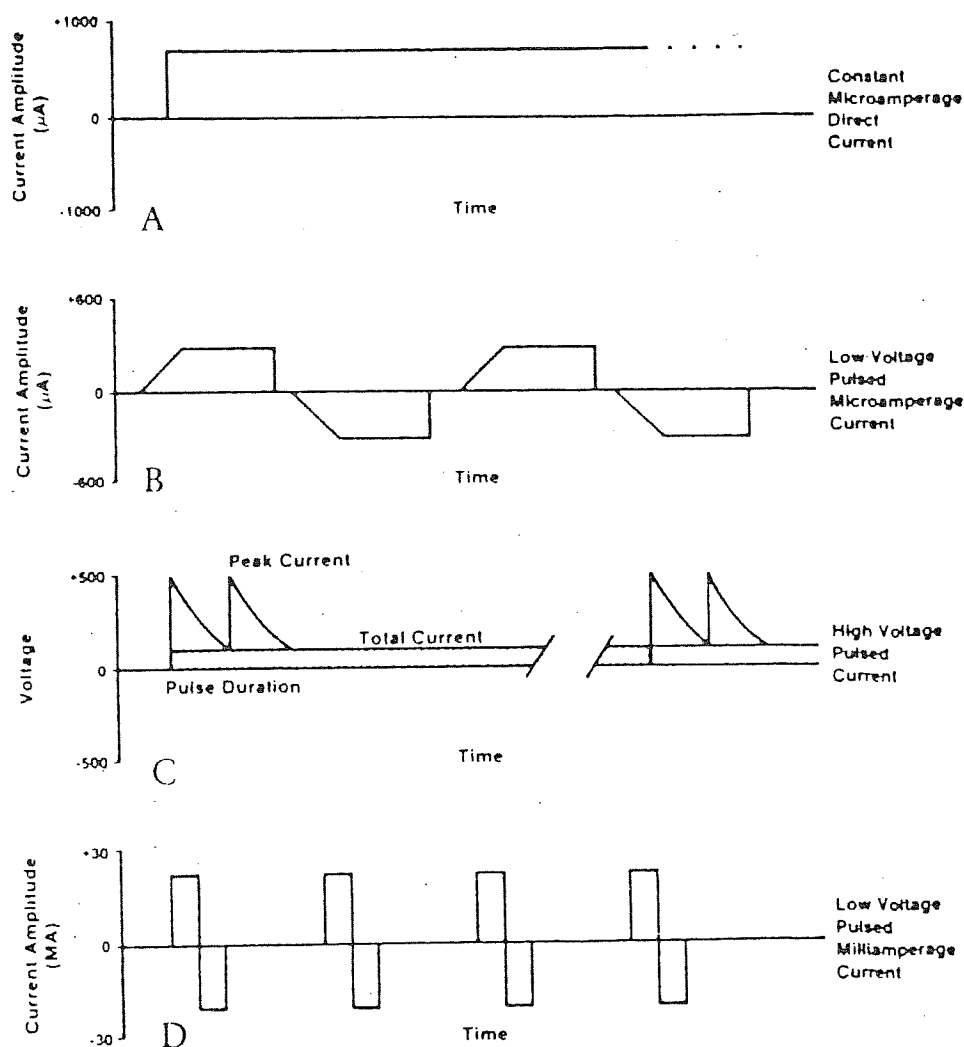


FIGURE 1. Four types of current used in the treatment of chronic wounds, as described in the literature. A, Continuous microamperage direct current. The polarity may be reversed. B, Low-voltage pulsed microamperage current. Polarity may be constant or alternately reversed. C, High-voltage pulsed current. Polarity may be reversed. D, Low-voltage pulsed milliamperage current. (Reprinted with permission from McCulloch JM, Kloth LC, Feedar JA. Wound Healing: Alternatives in Management. 2nd ed. © 1995, F. A. Davis Company.)

TABLE 2. Clinical Studies of Electrotherapy and Tissue Healing

	Current Type and Treatment	No. of Patients	No. and Type of Wounds	Treatment Time/Wk	Healing Rate/Wk (%)	Mean Healing Time (% Healed)
Continuous Microamperage D/C:						
Wolcott et al. <sup>61</sup>	200-800 $\mu$ A; cathode for 3 or more days, then anode.	67	Ischemic ulcers: 75 treatment 8 control	42 hr	Treatment: 13.4 Control: 5	9.6 wk (45%)
Gault and Gatens <sup>62</sup>	200-800 $\mu$ A; cathode for 3 or more days, then anode.	76	Ischemic ulcers: 100 treatment 6 control	42 hr	Treatment: 29 Control: 14.7	4.7 wk (48%)
Carley and Wainapel <sup>63</sup>	300-700 $\mu$ A; cathode for 3 or more days, then anode.	30	Indolent ulcers: 15 treatment 15 control	20 hr	Treatment: 18 Control: 9	5 wk (not reported)
Assimacopoulos <sup>64</sup>	50-100 $\mu$ A; cathode only.	3	Venous insufficiency leg ulcers: 8 treatment 0 control	168 hr assumed	Not reported	4.4 wk (100%)
Pulsed Microamperage D/C:						
Barron et al. <sup>65</sup>	600 $\mu$ A at 0.5 pps; cathode initially.	6	Pressure ulcers: 6 treatment 0 control	3 hr assumed	Not reported	4 wk (83%)
Wood et al. <sup>66</sup>	600 $\mu$ A at 0.8 pps; cathode initially.	74	Pressure ulcers: 43 treatment 31 control	12 min	Not reported	8 wk (58%)
Pulsed Milliampere DC:						
Kaada <sup>67</sup>	Low-voltage square wave TENS unit; 29.2 mA; cathode first, then polarity switched.	10	Dermal ulcers: 19 treatment 0 control	Not reported	Not reported	12 wk (100%)
Mulder <sup>68</sup>	30, 35, 40 mA; infected had cathode; noninfected had 3 days cathode, then anode.	47	Pressure, vascular, or surgical wounds: 26 treatment 24 control	7 hr	Treatment: 36 Control: 13*	Not reported (56% of initial size after 4 wks' treatment)
Feedar et al. <sup>69</sup>	29.2 mA at 128 pps; cathode first, then polarity switched.	50	Pressure ulcers: 26 treatment 24 control	7 hr	Treatment: 14 Control: 8.25	Not reported (44% of initial size after 4 wks' treatment)

Gentzkow et al. <sup>70</sup>	29.2 mA; cathode first, then polarity switched.	37	Pressure ulcers: 21 treatment 19 control	7 hr	Treatment: 12.5 Control: 5.8	Not reported (49.8% of initial size after 4 wks' treatment)
Various Currents:						
Baker et al. <sup>71</sup>	A: Asymmetric biphasic current: below motor response, 50 pps, 100- $\mu$ sec pulse duration. B: Symmetric biphasic current: below motor, 50 pps, 300- $\mu$ sec pulse duration. C: Micro current: 1 mA, 1 pulse, 10- $\mu$ sec pulse duration.	80	Diabetic ulcers: A: 29 B: 24 C: 20 19 control	7.5 hr	A: 27 B: 16 C: 17 Control: 17	Not reported
High-voltage Pulsed Current:						
Akers and Gabrielson <sup>72</sup>	Frequency and polarity not reported.	14	Pressure ulcers: 14 treatment 0 control	Not reported	Not reported	Not reported
Alon et al. <sup>73</sup>	Below motor response, anode used, 80 pps.	15	Pressure ulcers: 15 treatment 0 control	3 hr	Not reported	10.5 wk (80%)
Griffin et al. <sup>74</sup>	200 V, 500 $\mu$ A; cathode; 100 pps.	17	Pressure ulcers: 8 treatment 9 control	7 hr	Not reported	Not reported (80% of initial size after 4 wks' treatment)
Unger et al. <sup>75</sup>	150 V, 750 peak mA; cathode, 50 pps. After day six, 100 V, 500 peak mA; anode, 80 pps.	17	Pressure ulcers: 9 treatment 8 control	7 hr assumed	Not reported	Treatment: 51.2 days (88.9%) Control: 77 days (37.5%)
Unger <sup>76</sup>	150 V, 750 peak mA; cathode, 50 pps. After day six, 100 V, 500 peak mA; anode, 80 pps.	154	Unspecified wounds: 233 wounds 0 control	Not reported	Not reported	10.85 wk (89.7%)
Kloth and Feedar <sup>77</sup>	100-150 V (sensory), 500-800 mA; anode, 105 pps.	16	Pressure ulcers: 9 treatment 7 control 3 crossover	3.7 hr	Treatment: 46 Control: 11.6 Cross-over: 38	7.3 wk (100%)

NOTE: DC indicates direct current; pps, pulse per second; TENS, transcutaneous electrical nerve stimulator.

\*Estimated from graphs.

**TABLE 3. Protocol for Use of High-voltage Pulsed Current<sup>81</sup>**

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Inflammatory phase and proliferative/fibroplasia phase:
Cathode on wound
Frequency, 30 pps
Intensity, 100–150 V
60 min once a day 5–7 times/wk
Epithelialization:
3 days cathode followed by 3 days anode; continue the 3-day alternations
Frequency, 100–128 pps
Intensity, 100–150 V
60 min once a day 5–7 times/wk
Remodeling/maturation phase
Alternate polarity daily
Frequency, 60–64 pps
Intensity, 100–150 V
60 min once a day 5–7 times/wk

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sensation, the amplitude is submotor. The wound is treated for 60 minutes a day, five days a week. Sussman<sup>81</sup> outlines a somewhat different approach to applying HVPC, as shown in Table 3, in which the parameters are changed according to which phase of healing is being addressed.

## Polarity

Polarity has been mentioned in the previous discussions of the different types of electrical current used for healing tissue. Direct current, which is often cited in research, can produce electrochemical, pH, and temperature changes in cells and tissue. These changes may play a role in some of the tissue-healing and bactericidal effects that have been reported. Care must be taken with direct current because tissue damage may result from inappropriate and unsafe use. High-voltage pulsed current has a very short pulse duration, allowing for fewer pH, temperature, and other changes in the tissue. Since there is less risk of tissue damage with HVPC, it is a much safer electrical current to use clinically.

Another issue addressed in the literature and mentioned in this article is the switching of polarity during the use of electrotherapy for tissue healing. The switching of polarity appears to affect the healing process. However, more research is needed to determine what types of wounds and what circumstances warrant polarity switches.

## Electrode Placement and Other Considerations

Many considerations need to be taken into account when preparing a patient for electrotherapy to enhance tissue healing, such as infection control, cleansing and debridement of the wound, electrode usage, parameters, and the types of wounds to be treated. Infection control means ensuring that all

the materials that come into contact with the wound have been thoroughly cleaned and disinfected. Good hand washing and appropriate protective gowning and gloving protect the patient and the therapist or health-care giver. In a study of the efficacy of disinfecting the sponges and electrodes used in electrotherapy for wound healing, Kalinowski et al.<sup>82</sup> found that a common disinfectant containing dimethylbenzyl ammonium chloride was effective in disinfecting the sponges and electrodes. Their technique included immersing the electrodes and sponges for 20 minutes in the disinfectant diluted in water, followed by rinsing them for five minutes in clean, running tap water. This technique resulted in a 92% success rate for eliminating bacteria.

Before electrotherapeutic current is applied, the wound bed must be thoroughly cleansed to remove necrotic material, exudate, foreign material, medications, and heavy metals.<sup>80,81</sup> Cleansing of the wound promotes healing and prevents the inappropriate reaction of the current with any material or medication that may have been present in the tissue. Inspection of the wound before and after treatment is necessary to assess and evaluate the response to treatment.

Electrode considerations include the conductive medium and electrode size and placement. The conductive medium may be a sterile saline-soaked gauze under the electrodes, a saline-based hydrogel dressing, or another product. The main concern is the ability of the medium to conduct current safely and to control infection. Brown<sup>83</sup> discusses some of these electrode considerations as they pertain to the use of HVPC. For example, the treatment electrode is usually one quarter the size of the dispersive, or nontreatment, electrode. It should be noted that some types of electrodes can be cut to allow for this size differential, whereas others cannot.

The protocol used in some research on wound healing involves the placement of the anode (the positive electrode) proximal to the cathode (the negative electrode). The basis for this is Becker's concept of the "current of injury" and his demonstration that the human body has a positive polarity proximally, on the spinal axis, and a negative one distally, on the periphery.<sup>84</sup> Kloth and Fedar<sup>77</sup> use this protocol successfully in their research. Griffin et al.<sup>74</sup> do not follow this rationale for electrode

**TABLE 4. Contraindications to Electrotherapy<sup>79,81</sup>**

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Osteomyelitis
Cancer
Demand-type cardiac pacemakers
Pregnancy
Topical substances in the wound that would cause irritation, tissue toxicity, or allergic reaction

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NOTE: Electrodes should never be placed near the heart, phrenic nerve, carotid sinus, or laryngeal musculature.

placement and have found similar positive healing rates. Further research into appropriate electrode placement is warranted.

A review of the types of current used in electrotherapy and healing shows that there are many variations in the types of current and the parameters used. It can be confusing and difficult to sort out a beneficial and appropriate manner of applying therapeutic current to a patient. Reich and Tarjan<sup>85</sup> attempted to distill the research findings into common dosages. Recent findings were compared in terms of current density derived from the size of the electrode used and the current intensity. The authors found that a current density of 0.1–2.0 mA/cm<sup>2</sup> appears to be effective in enhancing tissue healing.<sup>85</sup> This finding leads to more questions on what parameters really are the most desirable to effect the healing of tissue. Further research is needed to get the root of these questions.

Finally, what types of wounds are appropriate for electrotherapy? The following wound types have been cited in the literature: pressure ulcers, diabetic ulcers, vascular ulcers (venous and arterial insufficiency), traumatic and surgical wounds, donor sites, skin and tissue flaps, and burn wounds. These and other types of wounds need to be studied further to delineate which current types and what parameters will successfully augment the healing process.

### Contraindications and Precautions

Before finishing the review of electrotherapy and its effects on healing, a look at the adverse effects, precautions, and contraindications is needed. Few adverse effects are cited in the literature, except for complaints of tingling or prickly feelings and occasional skin irritation.<sup>68</sup> Sussman<sup>81</sup> describes the possibility that electrotherapy may cause an increase in the pain of patients with peripheral vascular disease.<sup>81</sup> As mentioned earlier, the clinician must ensure that there are no foreign material, medications, heavy metals, or other topical substances in the wound that may hinder the treatment or adversely affect the care of the wound. In light of these possibilities, electrotherapy should be utilized with caution. Contraindications to the use of electrotherapy are listed in Table 4. Before a wound is treated electrotherapeutically, the patient should be screened for these conditions.

### CONCLUSION

Wound care and tissue repair is a fascinating and rapidly developing field. This issue of the Journal, devoted entirely to recent findings and directions in tissue repair, is a testament to this fact. New clinical techniques—utilizing biologic skin substitutes, growth factors, growth hormones, ultrasound, laser, thermal and hyperbaric modalities, electrotherapeutic currents, and others—need further exploration. The use of electrotherapy to enhance and augment healing has been supported by

the literature. There is a need for new research to be conducted to clearly outline the appropriate wounds to be treated, current types to be utilized, and parameter settings that produce the most beneficial outcomes for tissue healing. Research is also needed to develop new techniques for electrotherapy and other forms of treatment so that the field of tissue repair can be propelled into the 21st century.

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